Project	AtlantOS – 633211
Deliverable number	8.10
Deliverable title	Ship routing hazard maps
Description	This task will use outputs from the Copernicus Marine Environment Monitoring Service (CMEMS) to develop a system for ship routing hazard mapping. Starting from knowledge of the environmental fields affecting vessel seakeeping, the system will estimate hazard and cost associated to known routes in the Atlantic Ocean. The system will employ model analysis or reanalysis of sea state (wave height, period, and direction), hydrodynamics (near surface ocean currents), and meteorological (wind) models. The system will produce an objective route hazard assessment, based on UNIBO experience in hazard mapping and probabilistic approaches. The investigated routes will be selected based on the most relevant ones, according to the AIS (Automatic Information System) density maps. In particular, the existing CMCC ship routing code (VISIR) will be first of all validated through inter-comparison with analytical benchmarks and other published models. VISIR's functionalities will then be extended for optimizing the operational costs (bunker) of large ocean-going vessels sailing along routes compliant with IMO safety recommendations. The same approach will be extended to computation of vessel operational costs along the route. This information will build up a database, queried by the end-user through a graphical interface for visualizing customized maps of route hazard and cost for user provided parameters [D8.10]. The fitness of AtlantOS for ship routing will be analyzed with a dedicated report [D8.14].
Work Package number	8
Work Package title	Societal benefits from observing/information systems
Lead beneficiary	CMCC
Lead authors	Gianandrea Mannarini (CMCC)

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1. Background

Climate change and related global warming is affecting life on Earth, with a disruptive potential on well-being of people, functioning of societies, and political instabilities.
In its latest report, IPCC addressed the question of the feasibility of limiting global warming to 1.5°C over preindustrial levels (IPCC, 2018). This assessment was mandated in 2015 by the Paris Agreement (UNFCCC, 2015). The IPCC report states that about 1.0°C warming has already occurred. Furthermore, the impacts of 1.5°C warming would be appreciably lower than those of 2.0°C: for instance, by end of this century, 10 cm less sea level rise and a survival of 10-30% of the coral reef are expected, while it would be lost, to a large extent, under the 2.0°C scenario. At the same time, IPCC (2018) states that, in order to match the 1.5°C objective, net greenhouse gases (GHG) emissions should peak 2030 and vanish by mid-century. This would require a rapid technological and energetic transition at a global scale.
International shipping contributes with an appreciable share to the global emissions of GHGs (2.2% of them, according to Smith et al. (2014); like Italy and Spain together, according to the Edgar database[1]).
Shipping GHG emission responsibility is fully acknowledged by the International Maritime Organization (IMO), which has also recently approved an initial strategy for GHG emission reduction from ships (IMO, 2018a). Assuming as a baseline year 2008, the strategy envisions halving of the emissions by mid-century and reducing the carbon intensity by 40% by 2030. The definition of carbon emission intensity by shipping is still debated, but it could be operationally defined as the EEOI (Energy Efficiency Operational Indicator), i.e. as the ratio of CO_2 emissions to the transport work, where the latter is provided by the product of vessel deadweight and sailed distance.
To achieve these goals, the industry (UMAS, 2017 and OECD, 2018) indicates three possible lines of action:
1) Use of Alternative fuels - such as biofuels, hydrogen and ammonia;
2) Technological measures - such as hull design improvements, air lubrification, and bulbous bows;
3) Operational measures - such as ship route optimization, smoother ship-port interfaces, and increased ship size.

[1] http://edgar.jrc.ec.europa.eu/overview.php?v=CO2ts1990-2015

In the short term (i.e., next one or two decades), ship route optimization is probably a viable option. It can apply to both existing and new vessels. Furthermore, it seems to be favoured with respect to so called "speed optimization" or slow steaming, as the latter includes a risk of shifting transport of goods to other modes (such as aviation or terrestrial modes) and may damage distant Countries and liner ferry connections (IMO, 2018b). Ship route optimization has also been backed as an effective tool for GHG emission savings by the final event of a major European project on Sea Traffic Management (STM, 2018).

2. VISIR ship routing model

In order to contribute to the challenges posed by the reduction of GHG emissions by shipping, the VISIR[2] ship routing model[3] (Mannarini et al., 2016) has been further developed, adding new technical capabilities. The results have been validated through comparison to both analytical and model benchmarks. Preliminary results were published in Mannarini et al. (2018a) while a full-featured documentation is provided in two manuscripts submitted for peer review (Mannarini et al., 2018b,c). Their contents are only briefly summarized in this Section of the report.

2.1 Model developments

The main VISIR improvements regard: consideration of ocean currents together with waves for computation of the optimal ship tracks; increase in angular resolution in the numerical algorithm that defines the ship trajectories, time-interpolation of the input environmental fields. Furthermore, the procedure for generation of a navigationally safe graph has been re-designed and made more suitable for the Atlantic Ocean, while keeping into account coastlines and bathymetry. This is needed to ensure that the computed ship tracks avoid a passage into unsuitable shallow waters[4].
Furthermore, the VISIR dynamical safety constraint related to parametric roll has been updated for proper consideration of large vessels. This made the check on the loss of vessel stability in rough seas even stricter than within the previous VISIR version documented in Mannarini et al. (2016).
Finally, the optimal ship trajectories are assessed with respect to the energy efficiency of the voyage. This is quantified through the EEOI indicator established by the IMO in 2009, which represents the CO_2 emissions per transport work (IMO, 2009):

$$\mathrm{EEOI} = \frac{Cf * s * P * T}{DWT * L}$$

where the C_F is a conversion factor from fuel consumption to mass of CO_2 emitted, s is the specific fuel consumption, P is the engine brake power and T the sailing time. In the denominator, both the deadweight DWT and track length L appear. Variations of P are allowed by VISIR algorithm, while s is assumed to be a constant.
As mentioned in the introduction, the estimated carbon intensity by ship traffic needs to be globally reduced by at least 40 % before 2030, compared to 2008 values (IMO, 2018b). Thus, given realistic environmental conditions of currents and waves, we compute the EEOI savings of optimal tracks with respect to minimal distance (or: geodetic) tracks.

[2] VISIR is an acronym for "discoVerIng Safe and effIcient Routes"
[3] www.visir-model.net
[4] In order to use VISIR even in coastal domains, such as at the entrance of harbours, both a more resolved graph and more resolved environmental fields would be needed. In addition, data from the nautical charts should be employed for avoiding the obstructions and other constraints to navigation such as Traffic Separation Schemes.

2.2 Model validation

The validation of the VISIR upgrades introduced during AtlantOS is based on comparison to *i)* another path planner model and *ii)* analytical benchmarks for idealized environmental conditions.

The *i)* step has been realized though a comparison with a path-planning model developed at the Massachusetts Institute of Technology (MIT) (Lolla et al., 2014). The intercomparison experiment has been carried out in identical environmental conditions and time-dependent wave fields were considered. To start with, ocean currents were left out the experiment. The outcome of the exercise is documented in Mannarini et al. (2018b). The international collaboration of CMCC with MIT has been partly supported by AtlantOS.

The *ii)* step has been realized through the comparison of the analytical least-time trajectory with the VISIR solution in presence of a time-dependent flow. VISIR solution converges to the analytical one, also thanks to the higher angular resolution (another of the main VISIR advancements carried out by AtlantOS Task 8.3, cf. Sect 2.1).

3. Web Application

The new VISIR model version has been employed for computation of time-optimal tracks in the Atlantic Ocean, assessing the reduction in carbon intensity through the EEOI indicator. Environmental conditions for the year 2017 have been employed. They were represented through CMEMS analysis fields of ocean currents[5] and waves[6].
The vessel parameters employed refer to a container ship of about 33,000 tons deadweight and top speed of about 21 knots[7]. Such a vessel can use order of 1,000 $ fuel oil per hour, corresponding to emissions of about 10 tons CO_2 per hour, which is about twice the global-mean per-capita emissions of one year[8]. A typical transatlantic voyage can last 150-350 hours. It is then self-evident that even savings in the voyage duration of few percent can be appreciable in terms of both environmental impact and economic cost.
For each route, 72 vessel departure dates in 2017 have been considered. This allowed some sampling of environmental conditions for the met-ocean variables (waves and currents). Each route results into a bundle of tracks of various duration and length, each of them being optimal for the actual departure date it refers to (cf. Figure 1).
Finally, the EEOI values resulting from optimally choosing the trajectory on the basis of waves and currents have been compared to EEOI of the tracks of minimal length (which, in the open ocean, would be arcs of great circles). The so defined EEOI savings exhibit a significant regional, intra-monthly, and seasonal variability. The annual mean savings value for year 2017, ranged between 1 to 8 %. The monthly mean savings value for specific routes, such as Algeciras – Norfolk or Buenos Aires – Port Elizabeth, can at times exceed 20 %.
The database of the resulting optimal tracks and timeseries of EEOI savings can then be browsed through a web application. It employs code written in various languages as reported in Table 1

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[5] GLOBAL_ANALYSIS_FORECAST_PHY_001_024
[6] GLOBAL_ANALYSIS_FORECAST_WAV_001_027
[7] Vessel parameters were provided by a ship company, as acknowledged in the Conclusions.
[8] https://data.worldbank.org/indicator/EN.ATM.CO2E.PC?end=2014&start=1960&view=chart

Table 1 Languages employed for realizing the web application www.atlantos-visir.com

webApp functional component	Coding languages
dynamic server-side	php
client-side	javascript, jquery
presentation layer	html, css, bootstrap
cartography	Google map API v3

Furthermore, a responsive design has been employed, allowing to easily visualize and use the service on both tablets and mobile phones.
The web application can be freely accessed at the URL http://www.atlantos-visir.com/ .

In Figure 1, a detail of the bundle of tracks for the 72 departure dates in 2017 of a specific route is displayed. This proves the capacity of the model to avoid landmass and conveys the amount of spatial variability of the tracks. The relative EEOI savings of the optimal tracks are also shown by the web application. Clicking on the track of interest, one can retrieve the individual track's EEOI saving, as shown in Figure 1.
Finally, the monthly mean value and month extrema of the EEOI savings are displayed in a chart below the map, as shown in Figure 2.

The routes chosen for the web application span both Hemispheres, and include ten among transatlantic voyages and shorter sea routes.

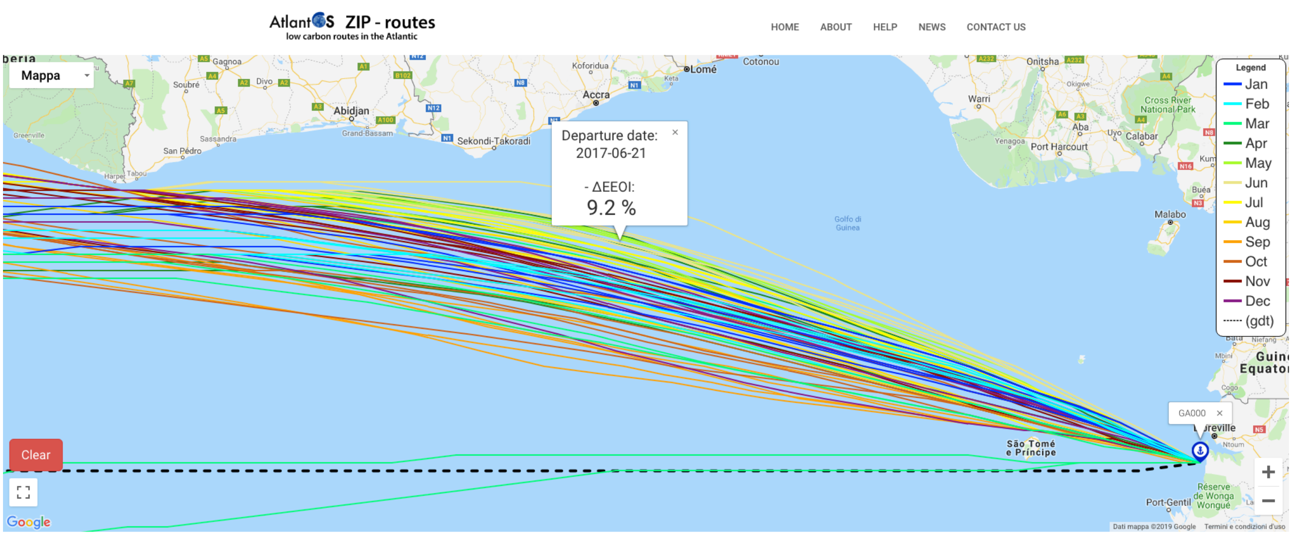

Figure 1 A detail of the bundle of optimal tracks between Mindelo (Cape Verde) and Genoa (Italy) in the vicinity of the Canary Islands. The shortest distance (or: geodetic) track is displayed as a black dashed line. All tracks correctly avoid the landmass. The info window displays departure date and relative EEOI saving for the selected track.

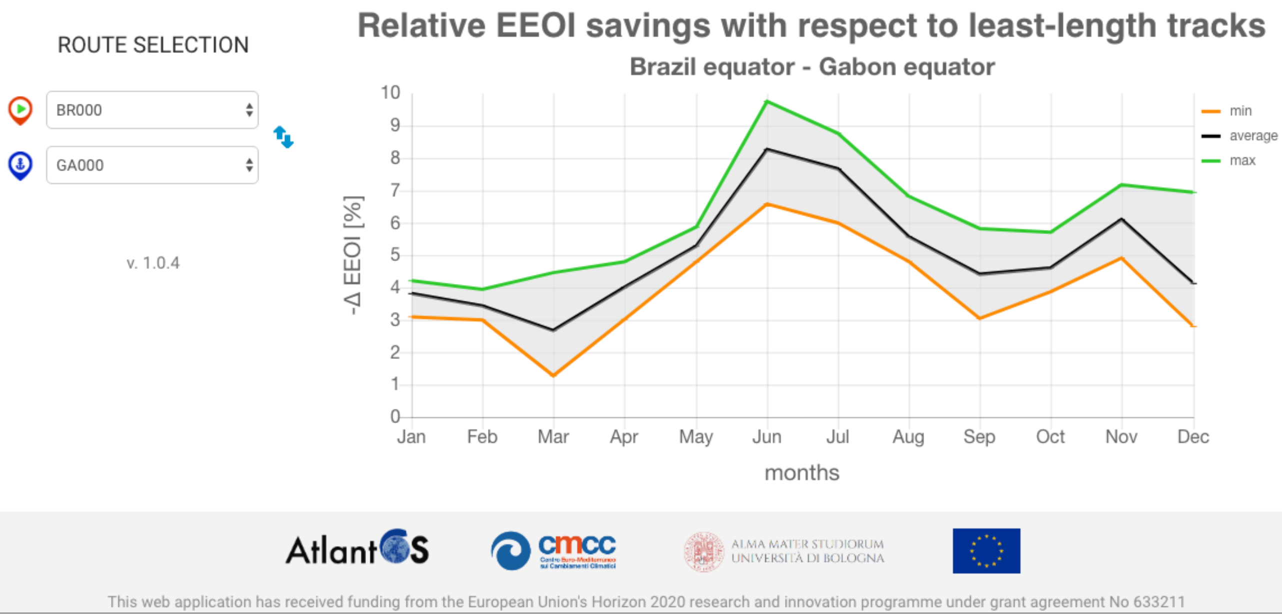

Figure 2 Left: Route selection pane; Right: linechart containing the relative EEOI saving along the months of the year for the route in Figure 1. The green, black, and orange line define the maximum, mean, and minimum value of the EEOI saving in each month respectively.

4. Meeting the deliverable objectives

The present deliverable meets all the project objectives but with some modifications with respect to the original text, in particular:

a) The bunker cost is replaced by the CO_2 emission savings, i.e. EEOI saving, of the optimal tracks;
b) The mapping is realized as the bundle of safe tracks, given a number of departure dates in 2017.

In *a)* the assumption is that bunker cost is proportional to the CO_2 emissions but we believe that, at this stage, it is more important to show that efficient and safe ship routing reduce CO_2 emissions. Maritime CO_2 emissions attained increased attention at a global level, also thanks to the latest resolutions of the Marine Environment Pollution Committee (MEPC) of IMO. In particular, in April 2018 MEPC72 approved an initial GHG reduction strategy (IMO, 2018a). One of its ambitions is "to reduce CO_2 emissions per transport work, as an average across international shipping, by at least 40% by 2030, pursuing efforts towards 70% by 2050, compared to 2008".

Concerning *b)*, the adopted approach makes use of the notion of decorrelation time of ocean currents (Lumpkin et al., 2002) for sampling the statistical variability of the environment. Departure dates at a 5-day distance ensure that the ocean flow experienced by each track has minimum correlation to the flow experienced by tracks departing on other dates. For waves, the timescale for decorrelation of ocean state is even shorter. Since each track is also checked for both static (positive under keel clearance) and dynamic (parametric roll, pure loss of stability, surfriding/ broaching-to) safety constraints, resulting bundle of ship tracks avoid exposure to such hazards. This defines a framework of probabilistic hazard mapping and low-CO_2 emission routes.

5. Conclusions

AtlantOS D8.10 deliverable type is "DEC" which stands for "Websites, Patents filling, etc.". This report is just a companion of the main deliverable output consisting in the web application

http://www.atlantos-visir.com/

The web app contains its own help and support pages and Sect.3 of this report describes the main functionalities of the AtlantOS product developed. It is important to stress that the work done for this deliverable included significant scientific advancements in the VISIR ship routing model and in its validation, as briefly mentioned in Sect.2 and in two manuscripts currently under peer review (Mannarini et al., 2018b,c).

Challenges we came across

Task 8.3 had to cover the enormous gap between the challenging technical VISIR model developments required for validating and porting it to the Atlantic, including ocean currents, to the construction of a user-friendly tool for end-users. In fact, we started with VISIR for the Mediterranean Sea that employed just waves and was validated to a limited extent only. We developed a model working in the Atlantic, delivering also a tool that has the potential to assist the targeted end-users, who are supposed to comply with the new regulations for a more environmentally friendly business.
The resulting AtlantOS open-source ship routing model linked to CMEMS ocean forecasts and analyses can have long-ranging benefits, as already envisioned in the 2nd AtlantOS Science-Policy Briefing Paper[9].

Users / added value

The work has received a beneficial input from other H-2020 projects and stakeholders. For instance, the routes chosen for the VISIR computations were based on analysis of AIS data provided by Dimitris Zissis of BigDataOcean project (http://www.bigdataocean.eu/site/). The vessel parameters employed by VISIR were provided by Florian Aendekerk of Compagnie Maritime Belge (https://www.cmb.be/).
Furthermore, AtlantOS results were presented on Oct 22nd, 2018 at the International Maritime Organization (www.imo.org) in London. The presentation was done in the frame of the Italian side-event of the MEPC-73 meeting[10] which addressed, among others, the implementation of the initial strategy on GHG emission reduction from ships.

What comes next

VISIR model should be refined in terms of the capacity to represent the marine state (use of high-temporal resolution wave fields, employing also other wave spectrum components (such as swell), accounting for Stokes's drift in addition to ocean currents for computing vessel advection by the flow, use of wind fields). Also, a more accurate description of the mechanical interaction between the environment and the vessel, especially in reference to speed loss in waves and wind, is planned.
Furthermore, the transport work definition appearing in the denominator of EEOI is in fact vessel-type dependent, (IMO, 2009). However, in the Atlantic version of VISIR we just focused on container vessels carrying solely containers. The EEOI estimations could be generalized in order to include also dry cargo carriers and cruise ships.
The ultimate frontier of the service developed within Task 8.3 would be to switch from the assessment of EEOI savings based on historical environmental conditions (i.e., analysis fields), to an operational use based on forecast fields. This is presently hindered by the fact that the duration of most transatlantic passages (which can be even longer than one week) exceeds the maximum lead-time of the available forecast fields (5 days). To that end, an option is to employ re-routing, i.e., re-start the ship routing optimal trajectory algorithm several times, employing successive forecasts, started at different times along the voyage. Using ocean forecasts in place of analyses, together with the planned VISIR developments mentioned above,

[9] http://oceanrep.geomar.de/42251/1/D10.7.pdf

[10] http://www.imo.org/en/MediaCentre/MeetingSummaries/MEPC/Pages/MEPC-73rd-session.aspx

would enable a useful contribution to the implementation of the IMO resolution on decarbonization of maritime transport.

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Stakeholder engagement relating to Task 8.3*

WHO are your most important stakeholders?	Private companies • SME: Marine Traffic • large company: Compagnie Maritime Belge International organization • International Maritime Organization (IMO)
WHERE is/are the company(ies) or organization(s) from?	Private companies • SME: UK • Large company: Belgium International organization • UK
Is this deliverable a success story? If yes, why? **If not, why?**	Yes: it succeeded in employing datasets derived from ocean observations (CMEMS analysis fields) in order to estimate time and carbon intensity savings for the maritime transport. (related success story submitted to AtlantOS PCU)
Will this deliverable be used? **If yes, who will use it?** **If not, why will it not be used?**	Yes, for instance by shipowners for assessing the seasonal variability of potential EEOI savings in transatlantic passages.

NOTE: This information is being collected for the following purposes:

1. To make a list of all companies/organizations with which AtlantOS partners have had contact. This is important to demonstrate the extent of industry and public-sector collaboration in the obs community. Please note that we will only publish one aggregated list of companies and not mention specific partnerships.
2. To better report success stories from the AtlantOS community on how observing delivers concrete value to society.

*For ideas about relations with stakeholders you are invited to consult D10.5 Best Practices in Stakeholder Engagement, Data Dissemination and Exploitation.